AD-A285 656

IPFR

Institute of Plasma and Fusion Research

1994 Nonneutral Plasma Workshop

G.J. Morales

October 1994 PPG-1524

Affiliated with the Departments of:

Astronomy
Earth and Space Sciences
Electrical Engineering
Materials Science and Engineering
Mechanical, Aerospace and Nuclear Engineering
Physics

and

Center for Advanced Accelerators
Institute of Geophysics and Planetary Physics

UNIVERSITY OF CALIFORNIA • LOS ANGELES

1994 Nonneutral Plasma Workshop

G.J. Morales

October 1994 PPG-1524

University of California at Los Angeles
Department of Physics
Los Angeles, CA 90024-1547

ONR

To Appear in Comments on Plasma Physics and Controlled Fusion

1994 NONNEUTRAL PLASMA WORKSHOP

G.J. Morales

Physics Department
University of California, Los Angeles
Los Angeles, CA. 90024

A workshop dedicated to the study of nonneutral plasmas confined in traps addresses frontier topics in the dynamics of vortices, development of self-organization, role of shear, operation of positron traps, and dusty plasmas. A personal perspective is presented.

Key words: nonneutral plasmas, vortices, shear instabilities, dusty plasmas

The most recent workshop dedicated to the latest developments in the physics of nonneutral plasmas was held at the University of California at Berkeley during July 17-20, 1994. The first organized meeting on this subject took the form of a symposium held at the National Academy of Sciences in Washington, D.C. , during March 28-29, 1988. The purpose of that pioneering meeting was to define the broad outlines of the subject of nonneutral plasmas, to summarize the theoretical and experimental foundations of the emerging field, and to speculate on possible technical directions that could be followed by a new community of specialists. The most significant outcome of the symposium was in fact the identification of a small community of researchers who focused their attention on the basic properties of nonneutral systems. An extremely informative record of the technical presentations (11 invited talks) and the ensuing discussions is found in the AIP Conference Proceedings #175, edited by C.W. Roberson and C.F. Driscoll. An excellent introduction to the subject, updated to incorporate some of the technical results presented at the symposium, is found in the textbook by R.C. Davidson, "Physics of Nonneutral Plasmas", published by Addison-Wesley in 1990.

During July 20-24, 1992, the Plasma Science Committee of the Board on Physics and Astronomy of the National Research Council (NRC) organized a "Workshop on Nonneutral Plasmas in Traps" at the Beckman Center in Irvine, California. That workshop was attended by about 60 researchers many of whom had entered the field as a consequence of the 1988 symposium. Aside from the high quality of the presentations and the many interesting subjects discussed, the Irvine workshop introduced an important distinction that in essence redefined the broader field that was surveyed at the 1988 symposium. The organizers essentially separated the field of nonneutral plasmas according to energy! . The early all-encompassing view that nonneutral plasma behavior ranged from studies of free electron lasers and accelerators to anti-matter research was dropped. The motivation for dropping the high-energy systems is that the basic studies require delicate traps that have relatively low energy density, and which lend themselves better to the study of few-particle effects, correlations, and in fact to the investigation of novel nonneutral systems that are not plasmas. No conference proceedings were made of the Irvine workshop, but a survey and an assessment of the meeting should be found in a report to be issued by the NRC, hopefully before the end of 1994.

The Berkeley workshop was chaired by J. Fajans (UCB) with D. Dubin (UCSD) acting as co-chair. The meeting was held at the Clark Kerr campus of UCB in which a large, old-fashioned auditorium was used for the presentation of 24 invited talks. A total of 30 poster presentations were divided into two sessions and were arranged in a very comfortable setting, some outdoors, that were very conducive to one-on-one discussions. Lunch facilities were located at the Kerr campus close to the auditorium and the very convenient and pleasant accommodations allowed for excellent opportunities to develop informal contacts. The organizers deserve to be congratulated for running an ideal small workshop.

The workshop was attended by approximately 75 researchers who were invited to participate by a program committee that was voluntarily formed by members of the nonneutral plasma community at the annual meeting of the Division of Plasma Physics (APS) held in St. Louis during November 1-5, 1993. The majority of the participants had attended the previous meeting in Irvine, however, a very refreshing aspect of this workshop was the relatively large participation by graduate students. This was possible because the majority of the academic institutions engaged in nonneutral plasma research are located in California. In fact 40 of the participants were from California, which is to be compared with a total of 8 foreign researchers representing India, Georgia, Germany and Japan. Clearly, basic research in nonneutral plasmas has not expanded very rapidly outside the United States.

The subject matter discussed at the workshop had a healthy mix of topics predicated on the redefinition of this community that occurred at the previous meeting in Irvine. Again, the high energy aspects of nonneutral plasmas were left out and emphasis was placed on making contact with studies of systems composed of a small number of charges and the development of correlations as the temperature is lowered. There were about 30 papers whose content could be identified as mainstream nonneutral plasma studies, 5 papers were related to the formation and operation of positron traps, 10 papers dealt with issues of few-particle dynamics and correlated systems, and there were several papers that had some aspect in common with nonneutral plasmas, including very interesting results obtained with dusty plasmas.

Without question the most significant advance made in this field over the past two years is the development of extremely sensitive imaging diagnostics. The enhanced capabilities stem from the increasing sophistication in the operation of charge coupled devices, implementation of delicate laser fluorescence diagnostics, operation of ion traps, and new imaginative methods for laser cooling.

An area in which the increased sophistication in imaging has had profound consequences to the understanding of the physics is that of vortex dynamics, as exemplified in the talk by C.F. Driscoll (UCSD). In these experiments nonneutral electron plasmas are confined in what this community is now referring to as a "Penning-Malmberg" trap (essentially the trap that was developed in the dissertation of J. deGrassie at around 1975 and which relies on axial electrostatic confinement and uses a strong magnetic field for radial confinement within a metallic cylinder) . In these traps it is possible to generate controlled vortex structures that closely approximate the behavior of ideal point vortices. The dynamics of vortex merger is studied by analyzing beautiful pictures obtained by dumping the confined plasma onto a screen placed at one of the ends of the confining cylinder.

The new improvements in spatial resolution clearly indicate that during the process of vortex merger, fine-scale filaments develop and exhibit long-term persistence as they wrap around the core of the vortex. It should be mentioned that earlier studies by the same group had imaged these filaments as a continuous diffuse background. It is observed that during the nonlinear development of unstable diocotron modes, due to hollow radial profiles, fine-scale filamentation is also generated. By closely analyzing the time evolution Driscoll and his colleagues have identified that the key mechanism generating the filaments is nonlinear Landau damping, i.e., the process of beat-resonance whereby a higher mode transfers action to a lower mode. Driscoll presented very convincing pictures that illustrate the decay of the l=3 mode to the l=2 and furthermore showed a plot of the radial dependence that looked to this author to be very similar to an Airy function centered around a resonance location. This finding suggests that perhaps there exists a mathematical similarity in the description of this process to a recent study (S. Srivastava, et al. Phys. Plasmas 1, 567 (1994)) related to nonlinear Landau damping in nonuniform plasmas.

Another interesting aspect of the filaments observed in these experiments is that their lifetime is orders of magnitude longer than is expected from estimates based on shear spreading.

In a different experimental arrangement K. Fine (UCSD) observes that very narrow layers generated by the individual wires that inject electrons into the trap evolve into a configuration of very stable filaments surrounded by a tenuous background. The individual filaments do not merge, but rather they appear to decay (in time) smoothly into the background. In fact, at a certain stage in the process the system is reminiscent of a crystal made of five or six filaments. Combining these results leads to the conclusion that small-scale nonneutral filaments exhibit a meta-equilibrium and that the popular idea of passive tracer behavior does not apply to these systems.

The Driscoll group has also pursued an investigation of what is the final configuration achieved by a system that starts out with N-vortices. By comparing the measured final state with theoretical predictions, the experimentalists conclude that their system does not evolve toward a state of maximum entropy, but instead remarkable agreement is obtained with a theory that identifies the final state to be a state of minimum enstropy (i.e., a second moment of the profile). General skepticism was visible among the audience concerning this conclusion and the question arose as to what is the physical meaning of enstropy. Nobody volunteered a suitable explanation. It was also suggested that it may be possible to model the experimental result using a higher moment.

It was refreshing to learn that it is still possible to do significant research in this field without large resources, as exemplified in the very clever work reported by D. Eggleston (Occidental College). He uses a trap with a conductor that runs along the center of the metallic cylinder. The purpose is to generate a controlled radial

electric field whose strength depends on radial position. An electron beam is injected off-axis in order to investigate the effect of shear on a vortex. By changing the polarity of the center conductor two different configurations can be generated, one has favorable shear and the other does not. The experiment uses a CCD image to sample the spreading of the initial vortex as a function of applied electric field. The data is quite beautiful and reproducible. The results are compared with the theories of Moore and Saffman of 1971 and of Kida of 1981, as modified by Eggleston to approximate his experimental environment. It is found that the threshold value for the destruction of a vortex is in good agreement with the theoretical prediction, however, the detailed shape of the curve (lifetime vs. shear) leads Eggleston to conclude that there are important effects present in the experiment that are not included in the theory. In particular he believes that internal diffusion within the vortex results in the formation of tenuous filaments. The agreement with the predicted threshold value is believed to be the result of pure scaling, and not of any particularly sophisticated theory.

For many years it has been widely believed by workers in this field that the large confinement time (as large as days) obtained in cylindrical traps is a consequence of the strict conservation of canonical angular momentum imposed by the cylindrical symmetry of the walls, which in practice is achieved by careful construction. Since the Irvine meeting, the experimental group headed by J. Fajans at UCB has reported detailed studies that demonstrate that large confinement times can also be achieved with boundaries that significantly depart from perfect cylindrical symmetry. This apparent paradox was addressed by T. O'Neil (UCSD) in a new theory of confinement based on the principle of "extreme of total electrostatic energy". This elegant and more general formulation allows the description of equilibria without having to explicitly require azimuthal symmetry. In this theory off-axis states are viewed as a transition from negative to positive energy caused by a nonlinear frequency shift. O'Neil believes that this principle explains the findings of the UCB group as well as off-axis confinement studies performed within a cylindrical trap by Driscoll. O'Neil has also applied these ideas to nonneutral toroidal traps.

Fajans followed the presentation by O'Neil with a pictorial description of what he thinks is responsible for his observations. According to Fajans the theorem presented by O'Neil is powerful but it is not clear that maximum energy states are the whole story in his experiments. Fajans concludes from his simple pictures that the key to the stability of highly deformed systems is the determination of when the combined flows stagnate. The qualitative rule is that sharp corners are "bad" for stability.

Although truly noteworthy results have been obtained in the study of *nonneutral* plasmas confined in simple traps, there is one important topic that still defies understanding, both at the experimental and theoretical level, namely transport. This situation is particularly frustrating to plasma physicists because the transport of particles and energy in neutralized plasmas generated in complicated

(but highly successful) magnetic confinement devices continues to be a mystery. It has been the expectation of the plasma community at large that the simplicity achieved in nonneutral traps could yield a paradigm system in which transport processes could be fully understood. Unfortunately, after twenty years of investigation that goal remains elusive, which indeed points out how difficult it is to understand plasma behavior beyond linear response.

A summary of confinement scaling observed on several machines was presented in a poster by A. Cass (UCSD). Over a limited regime it is possible to find that confinement time depends on a pure ratio of two time-scales, namely the ratio (squared) of the rotation period to the axial bounce time. The scaling with magnetic field improves as the square of the strength, but in some of the machines a departure from this scaling is observed beyond a certain level. What appears to be consistent with all the studies at different institutions is that indeed the confinement time is inversely proportional to the square of the axial length of the plasma!. It is counter-intuitive, but for these systems the shorter traps perform better. It is worth keeping in perspective that the confinement time in tokamak devices is observed to exhibit the opposite behavior, i.e., it increases as the square of the toroidal length of the discharge.

T. O'Neil and his students are investigating the role of asymmetries at the ends of the plasma column and the consequences that these extraneous torques may have for plasma confinement. In fact, several studies were presented in which external methods are used to add torque to the plasma in order to overcome the unknown anomalous torques and thereby increase the confinement time. In a sense this concept is analogous to the spin-up experiments performed by R. Taylor in the CCT tokamak at UCLA in which a torque is applied through an external electrode and induces H-modes having an order of magnitude improvement in particle confinement.

Preliminary results were presented by R. Pollock (Indiana U.) on the application of an azimuthally propagating quadrupole electric field at the plasma edge to increase the number of confined particles for a fixed magnetic field. The goal is to generate a polarized, high density target for nuclear physics studies. As is usual with the application of RF to plasmas, Pollock reports that as the voltage applied to the antenna is increased, plasma heating develops and ionization takes place, thus limiting the parameter space in which enhanced confinement can be obtained. F. Anderegg (UCSD) reported the very recent observation that an ion plasma could be confined overnight by applying rotating electric fields.

R. Gould (Caltech) described an ingenious method for determining the electron temperature in a trap that operates with low magnetic fields. A sensitive receiver is used to listen to the ambient noise of the l=1 mode below the cyclotron frequency as the density decays. Multiple wall probes are simultaneously used to launch a signal at the same frequency in order to determine the absorption from the plasma. A calibrated noise source is used to determine the absolute value of the

signal. The experimental curves are fitted with Lorentzians and by invoking Nyquist's theorem a temperature is deduced. It is found that for the plasmas used this technique yields a temperature of 0.5 eV, which is consistent with the expected value, but unfortunately there is no other independent measurement that can corroborate this result. Using this technique to monitor the time evolution of the temperature as the plasma expands indicates that the temperature does not change, a result which is not understood. Gould also described measurements of the damping experienced by externally launched l=2 diocotron modes that are excited with short bursts. It is found that the results are different from the observations in the earlier work by J. deGrassie. The Caltech measurements show that at small amplitude the l=2 mode exhibits an exponential damping in time and as the amplitude is increased the equivalent behavior to trapping oscillations develops, with the bounce frequency scaling as the square root of the applied voltage. However, no sidebands were reported.

The Penning Fusion Experiment was explained by D. Barnes (LANL). The underlying motivation can be traced to the observation made several years ago by R. Hirsch that in a radially focused configuration, obtained by spherical grids held at a potential of 100 keV, a substantial number of neutrons were generated. Of course, the plasma community at large has been skeptical about such findings. Nevertheless, the Los Alamos group has reworked the idea of electrostatically confined fusion by replacing the grid with a spherical Penning trap. The concept appears to be a bit vague at this time, but the general idea is to have a spherical cloud of energetic ions whose radial expansion is stopped by the potential barrier provided by surface electrodes in a high-multipole arrangement. In a sense this fusion concept can be viewed as an electrostatic analog of a SURMAC device. Barnes remarked that at this stage it is not known what all the plasma physics processes will do to the focusing of the energetic ions, an effect which is critical for significant neutron production. So, the early goal of the experiment is to inject a cold electron beam through a small hole in one of the electrodes and attempt to generate a steady-state, spherical nonneutral plasma. Even this goal is difficult to implement because of the large electrostatic stress and the strict requirements to keep the field errors small. It was reported that the electron beam experiment is under construction and results are expected within a year. It is not clear yet what type of diagnostics can be used to probe these delicate systems.

Computer simulation of nonneutral plasma behavior is slowly becoming a part of this community. For a few years now our group at UCLA has been using particle-in-cell simulations to explore fast time-scale properties. At this workshop I reported on some results, obtained in collaboration with H. Ramachandran (IPR-India), which explore how a nonneutral stream reflects from an external barrier. It is found that a behavior analogous of the Bohm sheath condition plays an important role. When the speed of the stream falls below the speed of the Gould-Trivelpiece modes an extended potential step develops and causes the slow particles to reflect far from the external barrier. The extended sheath can be long-lived and executes relaxation oscillations for systems in which the stream speed is not regulated. S.

Neu (UCLA) presented a poster in which a particle-in-cell code is used to study the time evolution of the diocotron instability in slab geometry. It is found that in order to provide a theoretical explanation for the observed time evolution it is essential to perform an initial value calculation. Some of the modes exhibit a secular and oscillatory behavior but are stable. This temporal evolution can lead to erroneous conclusions about the true bandwidth of the instability. Excellent agreement is found between the simulation and the initial value analysis.

A. Aydemir (U. Texas) presented results obtained with a guiding-center computer simulation in cylindrical geometry. He investigates the time evolution of a ring of electrons in the plane perpendicular to the magnetic field. By selectively seeding the system it is found that vortices very similar to those observed in the experiments by Driscoll are generated. In particular the l=3 mode is seen to evolve into fine scale filaments. Aydemir finds that contrary to theoretical expectations the l=1 mode grows in the simulation, a result also observed experimentally by Driscoll. It was suggested by some participants that the reason for the growth seen in the simulation could be traced to discreteness or boundary effects not included in the conventional theory which predicts the mode to be stable. Aydemir acknowledged that the numerical growth rate is found to change with grid size, but he always obtains unstable behavior.

Significant progress has been made in the generation of positron plasmas as evidenced by the reports of three different experimental groups. R. Greaves described the results of the group headed by C. Surko at UCSD. Their scheme uses positrons from a Sodium radioactive emitter and are slowed down by a solid rare gas moderator. The use of these moderators is having a tremendous impact (solid Neon can cool positrons down to 7 degrees Kelvin) in this field. This group uses differential gas pressure to collide and trap the positrons within an electrostatic barrier. Using a Tungsten moderator they achieve a 40% trapping efficiency and are able to generate a positron cloud whose parameters are in the plasma state and exhibits a half-hour lifetime. The cloud can be manipulated and can be moved from a long confinement cylinder into a short quadrupole trap. Within this trap they can measure the spectrum of axial oscillations. They are using a fit to the normal mode analysis of D. Dubin (UCSD) to deduce the aspect ratio of the cloud. A very unusual preliminary result was presented of the interaction of an electron beam with the confined positron plasma. It is observed that as the beam density is increased there appears to be a resonant value that causes the dumping of the positron plasma out of the trap. At beam densities higher than the resonant value the good confinement is restored. It is ironic that these traps which were originally intended for other uses are yielding very exciting mainstream plasma physics results.

J. Gabrielse (Harvard) gave an update on the efforts of his group to generate a portable positron trap that can hold about 10^6 positrons at a density of 10^8 cm^{-3}, eventually intended for anti-matter studies and cooling of heavy ions . The record number of positrons that they have captured is about 16×10^3 and were confined for about 32 hours. The capture rate is about 2×10^4 per day and the non-thermal energy

distribution function has a cold peak of .6 eV, which needs to be reduced by a factor of 10 for the applications envisioned. Attempts to increase the number of confined positrons have resulted in the triggering of anomalous transport. Although the loss rate is small by plasma physics standards (about 510 per hour) this implies that in steady-state the total number is smaller by a factor of 100 than is needed for the applications. So, they are at a critical stage in which further progress requires an understanding of the basic mechanisms underlying the transport, a situation reminiscent of the current state of fusion research. Gabrielse thinks that the biggest problem is asymmetries and his near-term goal is to develop a more symmetric trap. That also seems to be the path that needs to be followed in improving fusion devices.

T. Cowan (LLNL) was very pleased to report that after five years of hard work they now have an operating positron trap. Positrons from a Linac are injected into a trap with a 60 kG magnetic field. They use time-of-flight and collisional cooling to trap the positrons in axial potential barriers that are timed in proper sequence. It is estimated that about 10^3 positrons are trapped per pulse. Because of the relatively high duty cycle of the Linac this group feels that their trap is an excellent tool for plasma physics studies that require a large number of positrons at high density. However, no specific experiment was discussed.

In the area of few-particle effects and correlations at low temperature B. Birkl (MPI fur Quantenoptik, Germany) presented spectacular results of unprecedented precision. This group uses a tabletop, toroidal quadrupole trap with a circumference of 15 cm. A small neutral beam of Magnesium atoms is injected into the trap where an electron beam is used to ionize the atoms. Singly charged ions are confined toroidally and their temperature is lowered by laser cooling (using the conventional Doppler-shift effect). An unknown process causes the ions to come to rest in the lab frame, i.e., the toroidal drift stops. Laser fluorescence is used to map the spatial structure of the resulting nonneutral system. At low concentration the ions line-up end to end forming a toroidal necklace. As the density is increased the system develops two strands and eventually 3-dimensional helices or spirals are formed. In the high density limit multiple shells develop radially and eventually their spacing is so small that it is not possible to resolve their structure. This group is working to implement a new cooling technique known as "polarization gradient cooling" which will allow them to reach lower temperatures. Their plans are to study quantum collective effects and the dynamical properties of crystal formation.

J. Tan presented an update on the work done in the cold traps at NIST. The recent emphasis has been in increasing the number of Beryllium ions that can be trapped. The maximum number that has been confined is about 4×10^4. It is estimated that under these conditions the correlation parameter $\Gamma = 600$. It is observed that the sharp shell structure, seen previously with a small number of charges, begins to disappear. Imaging the charge cloud indicates that as the number of charges is increased it achieves a football shape. The unusual aspect that the NIST

group did not anticipate, based on their understanding of the spheroidal shapes investigated by D. Dubin, is that the top and bottom of the football shape is flat. Some participants suggested that this feature may be due to the presence of a halo formed by ions of different mass. My impression is that this newly observed feature is quite similar to the structure identified as 'rails' in our early computer simulation of the relaxation and self-organization of a nonneutral plasma reported at the Irvine meeting [H. Ramachandran et al., Europhysics Conf. Abst. Vol 16c, Part III p-1839, Innsbruck 1992].

The NIST group is pursuing a collaboration with Gabrielse to develop a positron trap to study anti-hydrogen. They are also exploring the possibility of developing a "stored ion clock" whose accuracy would be 10^{-17} sec. Tan explained that a key problem is the time-dilation shift, which needs to be made very small. This requires that the nonneutral cloud must have very low rotation frequency and very small radius, which is the opposite behavior to that of well-confined nonneutral plasmas. So, an optimum shape for the cloud must be found to meet th- e requirements.

T. Peurrung described his experience over the past year (at Pacific Northwest Lab) in trying to understand how "Tandem Fourier Transform/ Ion Cyclotron Resonance" devices work. These devices have been developed by chemists and are used as mass (and relative concentration) spectrometers capable of a resolution of one part in 10^8. The method of operation consists of generating a charged cloud from an initial unknown sample, moving the cloud into a region with a large magnetic field and then applying an impulse. The purpose of the kick is to put the cloud into the high-frequency rotational branch of the nonneutral equilibrium. Electrostatic pick-up probes are used to record the time evolution of the cloud and by using a Fast-Fourier transform algorithm a beautifully detailed spectrum is obtained. Peurrung showed a picture of the spectrum of a crude oil sample exhibiting a very rich structure. The conclusion that can be drawn from Peurrung's talk and other comments by S. Barlow (Pacific Northwest Lab) is that there exists an opportunity to apply the understanding that has been achieved in the study of nonneutral plasmas to these devices. Presently their operation requires the attention of a Ph.D. scientist because there are many plasma-related effects that create unforeseen problems. If a good understanding can be achieved of the plasma effects then it may be possible to have a simple instrument that can be reliably operated by a technician. If this level of sophistication is achieved, a very large market is anticipated for these devices. Presently there are three companies that sell these instruments at a price of about $500k.

The subject of dusty plasmas was introduced in a very enjoyable talk by J. Goree (U. Iowa). The methodology consists of exposing micron-sized dielectric particles to a plasma and depending on the plasma conditions each grain can collect as many as 10^5 charge quanta. The catch is that the charge on a given grain does not remain constant since it can be throttled by the local plasma parameters. It is relatively easy to confine the dust, and several groups around the world have

implemented various schemes. Goree and his collaborators in Garching use RF electrodes to levitate the grains. By simply adding more dust it is easy and relatively cheap to vary the correlation parameter over a wide range $10^2 < \Gamma < 10^6$. The diagnostics is also simple. Goree showed some examples in which excellent images could be obtained with a flash lamp. Of course, lasers are also used and yield spectacular pictures. A movie was shown of the time evolution of the organized system using poly dispersive dust (i.e., a distribution of grain sizes is present). The global arrangement of the grains is essentially hexagonal, but very interesting time dependent features are observed. One consists of locally orbiting grains, and another is long-range meandering through the stationary lattice. Clearly, these systems can exhibit a great wealth of behavior that should keep workers in this area occupied for some time.

Another simple confinement scheme was described by S. Robertson (U. Colorado). It is known as a Kingdom trap and consists of a long rod passing through circular end caps. The center rod is biased and provides a radial (logarithmic) potential in which the mechanics of a few-body system can be investigated. His interest is to relate the results to astronomical problems(e.g., resonant perturbations on asteroids, spiral arm effects). Robertson uses falling grains of dust that are charged with an electron beam. The charged particles circulate about the center conductor and can be imaged with simple illumination techniques. The most interesting result found is that in a system of six particles the eccentricity of the orbits damps faster than it is predicted theoretically; the system evolves into circular orbits. It is speculated that the behavior could be related to density waves, but no definitive results were mentioned. In the future Robertson plans to replace the center rod with a sphere and hopes to trap a belt or charged dust grains. However, the sphere makes the light-diagnostics more difficult.

The details of the topics mentioned in this brief survey, as well as many other interesting presentations, are to be found in an AIP Conference Proceedings that should appear in print in 1995.

Next, I conclude with some personal impressions of this interesting workshop.

Optical imaging has moved this field into a new level of sophistication. It is now possible to image vortices, ion distribution functions, few-charge systems, and dusty plasmas. The usage of these diagnostics over the next few years will probably generate a set of better defined paradoxes that will stimulate new theoretical developments. In my opinion, probably a void will be filled in the area of kinetic effects, which has been ignored to a large extent because most of the diagnostics used in the past only sampled fluid properties.

The study of vortex dynamics continues to be very prominent and remarkably the properties of the diocotron modes are not yet fully understood. However, a significant step reported, the identification of mode transfer through

nonlinear Landau damping, may yield new insight into the nonlinear dynamics of these systems.

Personally, it is disappointing to see that relatively little progress has been made in the transport studies. Probably much is to be gained in this area by establishing better contacts with workers who are struggling with similar problems in neutral plasmas. In particular, the H-mode studies in tokamaks could provide a natural link between these two communities. It is in this arena that the absence of J. Malmberg is most visible.

There are hints that there is more involvement of computation in this field. However, there is clear need for more serious contributions and longer term planning for the development of specialized simulations that optimize the ever increasing computer power.

The experimental study of dusty plasmas is beginning to establish an interesting area for the inexpensive study of strong coupling and organization. This provides an ideal arena for contact with nonneutral plasma research.

It is exciting to see that the positron traps are addressing mainstream plasma topics. There are a lot of interesting plasma-related problems that could be investigated with these systems.

My general impression is that this is a field in which the experimental foundation is maturing and many exciting results are yet to be discovered. The intellectual health of the field, however, depends critically on the ability to inject a broader set of perspectives to the interpretation of experimental results.

G.J. Morales

Physics Department
University of California, Los Angeles
Los Angeles, CA 90024